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ANALYSIS OF REFRIGERANTS USED IN SUPERMARKET COMMERCIAL EQUIPMENT AND THE POTENTIAL FOR INCREASING ENERGY EFFICIENCY AND REDUCING ENVIRONMENTAL IMPACT

Refrigerants used in the commercial equipment of supermarkets are the object of the research. The Montreal Protocol calls for a complete phase-out of hydrochlorofluorocarbons (HCFCs) by 2030, and the Kigali Amendment regulates the use of hydrofluorocarbons (HFCs) from 2019. Developed countries began phasing out HFC use in 2019, while developing countries plan to freeze HFC consumption from 2024. These global efforts are aimed at reducing the depletion of the ozone layer and combating climate change. The number of supermarkets in the world varies greatly: in Europe they number from 110 thousand to 115 thousand, and in China – from 65 thousand to 70 thousand, which reflects various needs in refrigeration equipment. Stringent environmental regulations are forcing the commercial refrigeration sector to remain globally competitive. Modernization of supermarkets using natural refrigerants is important for solving emerging challenges. The results of the study show significant improvements in energy efficiency ratio (EER) and coefficient of performance (COP) when using a mixture of hydrocarbons (R290: 85 %, R600a: 15 %) compared to traditional refrigerants R404a, R449a and R502. Specifically, at the evaporation temperature of T_{evap} = –10 °C, EER increased by 38–44 % and COP by 26–31 % compared to R404a and R449a, respectively. At T_{evap} = –25 °C, EER increased by 17–34 % and COP by 2–22 % compared to R404a and R449a. Additionally, compared to R502, the hydrocarbon blend showed a 38–44 % increase in EER and 28–31 % COP at Tevap = –10 °C, and a 17–34 % increase in EER and 5–22 % COP at T_{evap} = –25 °C. These results highlight the advantages of the hydrocarbon mixture at different evaporation temperatures, indicating its potential to improve energy efficiency in refrigeration applications. The obtained data suggest the possibility of a wider application of the mixture of hydrocarbons in commercial refrigeration plants, offering both improved performance and compliance with safety regulations.

Keywords: *propane, isobutane, refrigerant, hydrocarbons and their mixtures, fire hazard, commercial refrigeration equipment.*

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1. Introduction

Today, in the conditions of globalization, environmental regulations regarding refrigerants play an important role in determining sustainable practices in various industries. One of the key documents is the Montreal Protocol [1], which is an international agreement aimed at phasing out ozone-depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). The Kigali Amendment [2] emphasizes the need to reduce the production and consumption of hydrofluorocarbons (HFCs), which are powerful fluorinated gases. Complementing these global efforts are regional regulations such as the EU F-Gas Regulation [3] and national legislation such as the US Clean Air Act [4] and Japan's Hydrofluorocarbon Disposal and Disposal Act [5]. These regulations set quotas, bans and standards for the circulation, use and disposal of refrigerants, encouraging industries to adopt more environmentally friendly practices. Understanding these regulations is important for businesses around the world, as compliance not only protects the environment, but also drives innovation in sustainable refrigeration technology.

The data provided shows the breakdown of energy consumption across sectors, including lighting, HVAC (heating, ventilation and air conditioning), refrigeration, hot water and others. In particular, refrigeration equipment [6] has the largest share – 47 %, followed by lighting – 27 %, HVAC – 13 % and others – 10 %. The consumption of hot water is a smaller share – 3 %. There is also a trend in the supermarket sector to use refrigeration systems as heat pumps to use heat. This highlights the importance of energy consumption and the role of refrigeration systems in energy efficiency efforts [7], especially in supermarkets.

The statement that supermarkets consume about 3 % [8] of national electricity production highlights the significant energy needs of these retail establishments in the context of national energy consumption. This is important for energy consumption research and energy efficiency initiatives, as it highlights the significant impact supermarkets have on the overall energy landscape. Energy consumption by supermarkets is an important topic for developing strategies to optimize energy use, reduce environmental impact and increase energy sustainability at both local and national levels. It also highlights the importance of improving energy efficiency in the retail sector to meet wider energy targets and reduce the environmental footprint of commercial activities. Therefore, investigating the factors that contribute to electricity consumption in supermarkets and identifying opportunities for improvement are important to advance energy management research and sustainable practices.

With the update of EN 60335-2-89 [9] in August 2022 and ongoing efforts to bring it into line with the Machinery Directive 2006/42/EC, there is a need for clarity and consistency regarding the application of the regulations on flammable refrigerants. Currently, the limit for flammable refrigerants is set at 150 g, following the requirements of the general standard EN 378 [10] for higher charge requirements. However, difficulties arise due to different implementation deadlines for IEC 60335-2-89 by national authorities, different implementation deadlines and local adjustments of content to meet specific regional requirements. This variability can lead to uncertainty regarding the application of regulations and requirements that must be met for the sale of equipment in different territories. Solving these problems is important to ensure compliance with safety standards and promote the smooth circulation of refrigeration products on European markets.

Industries are actively exploring methods of energy conservation through improved temperature management. Despite slower progress in some regions, this highlights the impact of the crisis on improving efficiency and facilitating the adoption of new technologies. The impact of new standards and technologies may not be immediately apparent, with improved efficiency [11] and reduced energy intensity over time. Especially in Europe and other regions, governments have implemented complex rules and regulations aimed at reducing energy needs, while consumers and businesses are responding to rising costs by implementing energy-saving measures. This highlights the importance of sustained efforts and cooperation between governments, industries and consumers to achieve long-term energy efficiency goals and mitigate the effects of the energy crisis.

The company believes that promptly solving problems with refrigeration units is important to prevent food losses. The information provided highlights the significant contribution of the food system to greenhouse gas (GHG) emissions, ranging from 21 % to 37 % [12]. These emissions occur at various stages of the food system, including agriculture, land use, storage, transportation, packaging, processing, retail and consumption.

According to the key safety standards for refrigeration systems (EN 378, ISO5149 [13–15], EN 60335-2-89 [9]), these standards establish national regulations and ensure compliance with safety and environmental protection requirements in the refrigeration industry. Therefore, *the purpose of this work* is to conduct an energy audit of commercial refrigeration equipment (medium-temperature and low-temperature units), identify the energy potential and propose a viable solution – switching to hydrocarbon refrigerants [16]. This approach is aimed at increasing energy efficiency and reducing the impact on the environment while complying with established environmental regulations.

2. Materials and Methods

An energy audit of commercial refrigeration equipment was conducted, which allowed to determine its energy potential. A thermodynamic analysis was also performed to determine the efficiency of refrigerating units operating with different refrigerants for medium and low temperature units.

According to the EN 378 standard, the use of flammable refrigerants directly depends on the volume of the room where the refrigeration equipment is located and the mass of the flammable refrigerant. If the charge exceeds 0.15 kg, a sudden refrigerant leak should not increase the average concentration in the room above the practical limit of 0.008 kg/m^3. The volume of the room determines the total size of the charge. This can be determined using equation (1) for calculating the maximum permissible mass of flammable refrigerant in one circuit [10]:

$$M_r = 0.2 \cdot LFL \cdot V_{room}, \quad (1)$$

where M_r – maximum permissible amount of refrigerant per individual refrigeration circuit (kg); V_{room} – room volume (m^3); LFL – lower limit of the explosive concentration of the refrigerant (kg/m^3) from the table.

To prevent stratification of the refrigerant and the formation of explosive concentrations at lower levels in the event of a catastrophic leak, it is necessary to provide an adequate volume of air from the fan associated with the cooling system. This air volume must meet the minimum requirements defined in equation (2) for calculating the air volume in the event of an explosive refrigerant release:

$$M_{air} = C \cdot \left(\frac{M_r}{LFL} \right), \quad (2)$$

where C=17, when the evaporator fan in the air conditioner provides air flow into the room, or C=20, when the condenser fan in the refrigeration unit provides air flow into the room.

3. Results and Discussions

3.1. Results. Statistics on the use of different types of cooling equipment are of great importance. Due to the growing demand for technologies that reduce carbon dioxide emissions and protect the environment, manufacturers are currently working on creating more efficient and environmentally friendly cooling systems. In addition, government initiatives aimed at the development of advanced systems are expected to increase. Supermarkets and small shops typically use significant amounts of refrigerants with high GWP values. The traditional and prominent refrigerants in commercial supermarket equipment are R404A, R502a and R449a. These refrigerants are used in separate direct expansion systems for medium and low temperature units. To compare the efficiency of R449a, R404a, R502 and a mixture of R290 (85 %) and R600a (15 %) in a vapor compression system, the following results are presented. Some physical parameters and environmental impact parameters are given in Table 1.

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Table 1

Properties and environmental impact of selected refrigerants

Refrigerant	Molecular weight, kg/kmol	Boiling point, °C	Critical temperature, °C	Critical pressure, MPa	Toxicity class	Flammability class	GWP
R404a	97.60	–46.5	72.04	3.72	A1	1	3922
R502	111.63	–45.6	82.1	4.07	A1	1	4300
R449a	87.2	–46.0	87.2	4.44	A1	1	1282
R290 (85 %) R600a (15 %)	45.75	–39.38	103.8	4.32	A1	3	3

Equipment used for existing refrigerants does not need to be modified or changed to handle hydrocarbon refrigerants. Since no conversion is required, hydrocarbon refrigerants are an ideal solution for systems that previously used gases such as R502, R449, R404a and others.

Energy savings in refrigeration equipment can be achieved by using more efficient refrigerants and reducing leaks in cooling systems. This covers not only the selection of the most suitable type of working substance, but also the study of the possibility of implementing systems that use two refrigerants (primary and secondary) to optimize the operation of the system. Refrigerant leak cleaning also plays a key role in this process, leading to significant reductions in energy consumption and increased system efficiency. For cooling systems that use hydrocarbon refrigerants, this is also a safety issue. Hydrocarbon refrigerants in refrigeration units or car air conditioners consume less energy than fluorocarbon refrigerants. This provides several advantages:

– reducing the operating costs;

– reducing the load on the compressor, which leads to less wear and prolonging the service life of components, as well as reducing leaks;

– reducing energy consumption, which means less use of coal fuels and reducing the rate of global warming.

For thermodynamic analysis, the P–h diagram was used to construct the operating cycle of the cooling machine for each of the refrigerants (Fig. 1).

The established operating conditions of refrigerants were selected for different types of equipment – for medium and low temperatures. Operating parameters for medium temperature cooling.

Data on enthalpies for selected refrigerants for two modes of operation of the equipment – for medium temperature (–10 °C) and low temperature (–25 °C) – were entered in Table 2.

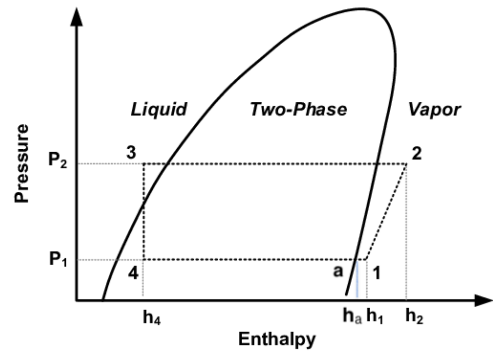

Fig. 1. P–h diagram for a vapor compression refrigerator

Next, the energy efficiency coefficient (*EER*) and performance coefficient (*COP*) parameters were calculated for these refrigerants, the results are shown in Table 3.

Data in Table 3 were illustrated in Fig. 2 (Imagined with AI). From these data, it follows that when using a mixture of R290 (85 %) and R600a (15 %) compared to R404a, the *EER* increased by 44 % and the *COP* by 26 % (T_{evap}=–10 °C), and respectively by 34 % and 22 % (T_{evap}=–25 °C). Comparing the hydrocarbon mixture with R449a refrigerant, it can be seen that *EER* increased by 43 % and *COP* by 31 % (T_{evap}=–10 °C), and respectively by 6 % and 2 % (T_{evap}=–25 °C). Additionally, comparing the hydrocarbon refrigerant with R502, the *EER* increased by 38 % and the *COP* by 28 % (T_{evap}=–10 °C), and by 17 % and 5 % (T_{evap}=–25 °C), respectively.

Table 2

Value of enthalpy at the points of the theoretical working cycle of a vapor compression refrigerating machine

Enthalpy	R404a, kJ/kg		R449a, kJ/kg		R502, kJ/kg		R290 (85 %), R134a (15 %), kJ/kg	
	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C
1	373	359	400	395	368	360	460	450
2	405	412	440	448	400	404	515	550
3	250	250	252	252	247	247	175	175
4	250	250	252	252	247	247	175	175
a	362	355	394	383	364	357	455	440

Note: T_{evap} – the evaporation temperature

Table 3

EER and COP parameters for refrigerants in different operating modes

Parameters	R404a		R449a		R502		R290 (85 %), R600a (15 %),	
	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C
EER	2.12	1.19	2.15	1.5	2.22	1.36	3.07	1.60
COP	2.93	1.83	2.83	2.21	2.89	2.15	3.71	2.25

Note: T_{evap} – evaporation temperature; *EER* – energy efficiency ratio; *COP* – coefficient of performance

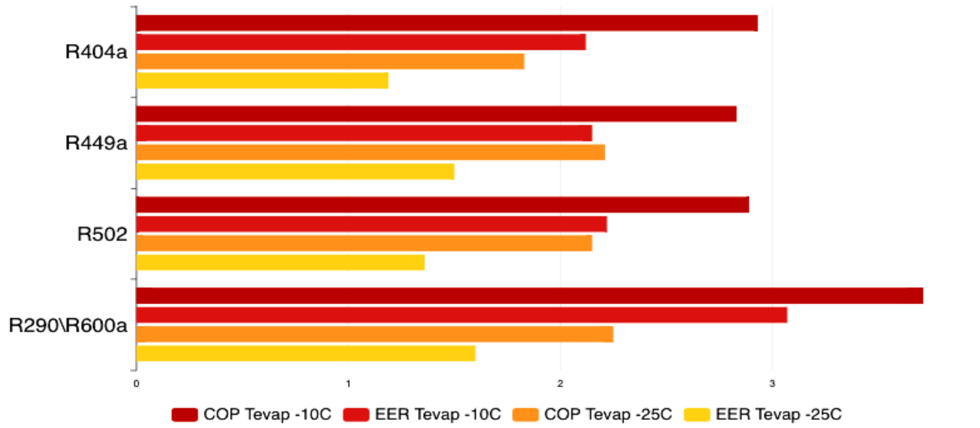

Fig. 2. *EER* and *COP* parameters for refrigerants in different operating modes

As a result of the comparative analysis, it was established that according to the EER and COP indicators, the hydrocarbon mixture as a refrigerant has a more effective performance than chemical refrigerants, due to such characteristics as a high specific heat of evaporation, the data are indicated in Table 4.

On experimental equipment (refrigerating showcase with dynamic evaporator blowing), it was established that when replacing R404a refrigerant with a mixture of R290 (85 %) and R600a (15 %), less amount of this mixture is required. The initial mass of the refrigerant was 360 grams, while the mass of the mixture of R290 (85 %) and R600a (15 %) was 142 grams, which is 2.5 times less. The lower limit of the explosive concentration of the mixture of refrigerants is given in Table 5.

It is recommended that the fan only run during the compressor cycle, as the potential for catastrophic leakage during off-cycle is minimal. Alternatively, the fan should be connected to a leak detection sensor that activates the fan only when a leak is detected.

3.2. Discussions. The growth of *EER* and *COP* is influenced by a number of properties of hydrocarbon refrigerants, namely:

1. Hydrocarbon refrigerants such as propane (R290) and isobutane (R600a) have significantly higher thermal conductivity compared to hydrofluorocarbons (HFCs). High thermal conductivity means that heat can be efficiently transferred through the refrigerant, speeding up the cooling or heating process.

2. Hydrocarbon refrigerants have a lower viscosity, which promotes better refrigerant flow through the system. This reduces flow resistance and lowers the load on the compressor, increasing the overall efficiency of the system.

3. Hydrocarbon refrigerants can absorb and release more heat per unit mass. This allows them to more efficiently transfer heat during phase transitions (for example, during evaporation or condensation), which is a key process in the operation of refrigeration and air conditioning systems.

4. Hydrocarbon refrigerants have an optimal pressure and boiling point, which allows them to work in a wider temperature range. This makes them particularly effective in conditions where it is necessary to maintain a stable temperature with minimal energy consumption.

Together, these factors provide more efficient heat exchange, which leads to lower energy consumption and increased performance of cooling and air conditioning systems. As a result, hydrocarbon refrigerants not only help save energy, but also ensure stable and reliable functioning of systems, which makes them preferable in modern climate installations.

The trend of expanding the use of hydrocarbons as natural working substances in refrigerating machines for various industries forces scientific laboratories and institutes to consider the new possibilities provided by hydrocarbons. Namely, mixed agents of different concentrations of components, the possibility of reducing the flammability of the working substance or the desire to fall within the safety limits of their use, established by ASHRAE for obtaining permission (license for implementation).

The problem for manufacturers of working substances is how to become in demand and competitive in accordance with the restrictions set by environmental regulations (environmental regulations) among the 3500 working substances available on the market.

To solve these issues, manufacturers turn to universities for the purpose of obtaining support from the scientific base, conducting research on the application of new installations (in particular, commercial refrigeration).

Table 4

Specific heat capacity of vaporization of refrigerants

R404a, kJ/kg		R449a, kJ/kg		R502, kJ/kg		R290 (85 %), R134a (15 %), kJ/kg	
T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C	T_{evap}=–10 °C	T_{evap}=–25 °C
112	105	142	131	117	110	280	265

Table 5

The lower flammability limit (*LFL*) of the refrigerant explosive concentration (kg/m^3) from the table

Refrigerant	LFL		Self-ignition temperature
	By volume, %	By mass, kg/m^3	°C
R290 (85 %), R600a (15 %)	1.5	0.026	460

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These results show the possibility of using mixed working substances in the commercial cold of medium supermarkets (3800 m^2), for small supermarkets (400–1000 m^2) and mini supermarkets (185–300 m^2).

In turn, the use of hydrocarbons will not only reduce the impact on the environment, but also reduce the cost of the refrigeration system (cheaper refrigerant, less amount of refrigerant filling the system).

The obtained results of the study of working substances allow to consider the possibilities of using hydrocarbon mixtures in commercial cold for portable medium-temperature (0+4) and low-temperature units (–30–18), which distinguishes them from the existing offers on the market.

3.2.1. Practical relevance. The proposed hydrocarbon mixtures can be used in transport for air conditioning, as well as in commercial refrigeration (medium and small supermarkets and minimarkets). This study can be useful for the production of refrigeration equipment. From the results of the study, it can be seen that when switching from HFC refrigerants to natural refrigerants, which consist of mixtures of hydrocarbons, manufacturers of refrigeration and air conditioning equipment do not need to significantly change the design of the equipment, but there is a need to install leak detection sensors if necessary. It is also possible to switch from HFC refrigerants to hydrocarbon refrigerants on already operated equipment.

3.2.2. Research limitations. Mixtures of hydrocarbon refrigerants can be used in low-temperature, medium-temperature and high-temperature refrigeration and climate equipment.

3.2.3. The impact of martial law conditions. Martial law in Ukraine reduces and limits the recruitment of necessary specialists, as the refrigeration sector is mainly staffed by men of draft age with HVAC&R systems, which creates a global shortage of qualified personnel.

3.2.4. Prospects for further research. It is planned to create two pilot projects (medium-temperature and low-temperature refrigeration plants) for commercial refrigeration and conduct a number of field studies on the proposed mixtures and a number of refrigerants that exist on the market. This is necessary for consideration of a comparative analysis together with the possibility of utilizing the waste heat of the refrigerating plant and maintaining system sustainability (System sustainability) in accordance with the environmental goals specified by the regulations, in accordance with the United Nations Environment Program – United for Efficiency (U4E) «Supporting developing countries, and countries with emerging market economies in accelerating the transition to energy-efficient and climate-safe equipment».

4. Conclusions

The possibility of using a mixture of R290 (85 %) and R600a (15 %) as a refrigerant to replace modern chemical refrigerants in commercial equipment was considered. An energy audit of medium and low temperature units was conducted, as well as an energy analysis of cooling systems. As a result of the comparative analysis, it was established that according to the EER and COP indicators, the hydrocarbon mixture as a refrigerant has a more effective performance than chemical refrigerants, due to such characteristics as a high specific heat of evaporation (Table 4). Hydrocarbon refrigerants have desirable thermodynamic properties that allow to achieve higher energy efficiency in cooling systems. This can help reduce energy consumption and, accordingly, lower operating costs throughout the life of the system. One of the important properties of hydrocarbon mixtures is the possibility of their use with existing components of cooling systems without significant changes in the design of the equipment. It is important to note that hydrocarbon refrigerants are flammable substances and their use requires additional safety measures and certification for installers and technical personnel of such systems. In the future, further practical studies of this mixture and comparison of actual performance indicators of cooling equipment are possible.

Conflict of interest

The authors have no conflicts of interest in relation to this study, including financial, personal, authorship or other, that could affect the study and its results presented in this article.

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The study was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors used artificial intelligence technologies within acceptable limits to provide their own verified data, which is indicated in the research results section.

References

1. About Montreal Protocol. *UN Environment Programme*. Available at: https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol
2. Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (2016). *United Nations Treaty Collection*. Available at: https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27&clang=_en
3. EU-Rules. Guidance on the EU's F-gas Regulation and its legal framework. *European Commission*. Available at: https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/eu-rules_en
4. Summary of the Clean Air Act. *United States Environmental Protection Agency*. Available at: https://www.epa.gov/laws-regulations/summary-clean-air-act
5. Hisashima, S. (2003). Fluorocarbon recovery and destruction: legislation. *Refrigeration, 78 (904)*. Available at: https://iifiir.org/en/fridoc/fluorocarbon-recovery-and-destruction-legislation-120757
6. Foster, A., Evans, J., Maidment, G. (2018). Benchmarking of Supermarket Energy Consumption. *5th IIR International Conference on Sustainability and the Cold Chain*. Beijing. doi: https://doi.org/10.18462/iir.iccc.2018.0006
7. Yakovleva, O. Y., Khmelniuk, M. G., Ostapenko, O. V. (2018). Energy efficiency projects. *Refrigeration Engineering and Technology, 54 (2)*, 25–29. doi: https://doi.org/10.15673/ret.v54i2.1099
8. Morrison, O. (2023). Inside the 'Supermarket of the Future' Promising to Waste Less Energy and Less Food. *FoodNavigator*. Available at: https://www.foodnavigator.com/Article/2023/06/30/Inside-the-supermarket-of-the-future-promising-to-waste-less-energy-and-less-food

9. *BS EN 60335-2-89:2010+A2:2017. Household and Similar Electrical Appliances. Safety Particular Requirements for Commercial Refrigerating Appliances with an Incorporated or Remote Refrigerant Unit or Compressor. European Standard*. Available at: https://www.en-standard.eu/bs-en-60335-2-89-2010-a2-2017-household-and-similar-electrical-appliances-safety-particular-requirements-for-commercial-refrigerating-appliances-with-an-incorporated-or-remote-refrigerant-unit-or-compressor/?gad_source=1&gclid=Cj0KCQjwjLGyBhCYARIsAPqTz1_1-CDsqY_nRdtye2HU2x-2Sb6EhkFxs50fWF9xbHFXVEKJtlfQ2w8aAoJDEALw_wcB
10. F-Gas regulation (2022). *IIR*. Available at: https://iifiir.org/en/news/latest-news-about-regulation-in-europe
11. Energy Efficiency 2023. *International energy agency*. Available at: https://iea.blob.core.windows.net/assets/dfd9134f-12eb-4045-9789-9d6ab8d9fbf4/EnergyEfficiency2023.pdf
12. Food security (2022). *Climate Change and Land*, 437–550. doi: https://doi.org/10.1017/9781009157988.007
13. ISO 5149-1:2014(en). Refrigerating systems and heat pumps – Safety and environmental requirements – Part 1: Definitions, classification and selection criteria. *ISO*. Available at: https://www.iso.org/obp/ui#iso:std:iso:5149:-1:ed-1:v1:en
14. ISO 5149-2:2014(en). Refrigerating systems and heat pumps – Safety and environmental requirements – Part 2: Design, construction, testing, marking and documentation. *ISO*. Available at: https://www.iso.org/obp/ui#iso:std:iso:5149:-2:ed-1:v1:en
15. ISO 5149-3:2014(en). Refrigerating systems and heat pumps – Safety and environmental requirements – Part 3: Installation site. *ISO*. Available at: https://www.iso.org/obp/ui#iso:std:iso:5149:-3:ed-1:v1:en
16. Global Hydrocarbons Market – Industry Trends and Forecast to 2030. *DataBridge*. Available at: https://www.databridgemarketresearch.com/reports/global-hydrocarbons-market

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